

1882, June 7, the summit was densely enveloped, and a heavy sleet began at 3:45 p. m., continuing at intervals until 8 p. m., when the wind, previously calm, suddenly began from the south at 20 miles per hour, and the sleet changed into heavy dense snow with a flash of lightning from the north. During the fall of sleet the peculiar singing or sizzling noise was heard on the wire. From 8:45 to 8:55 interesting electrical phenomena were observed, accompanied by dense driving snow, all of which then ceased suddenly.

1882, July 12, a thunderstorm, with hail and sleet. At 4 p. m., during the heaviest hailstorm, and when the wind died down to a calm, the observer went out to examine it as it fell on the roof in a deafening storm. The largest of the hailstones were an inch in diameter, of a balloon shape, not round and much harder than any ever seen by the observer, requiring a heavy blow with a rock to crack them.

1883, June 24, sleet and hail fell from 1 p. m. to 2:30 p. m. Some of the larger hail was fully one and a quarter inches in diameter and was very peculiar both in shape and composition. There were no icy layers or rings of ice, but the whole body of the stones was of a light porous nature. In shape they resembled a balloon, the smaller end coming nearer to a point. The smaller stones were nearly perfect spheres.

1885, August 29, thunderstorm from the northeast moving southward from 5:45 p. m. to 6:12 p. m., accompanied by sleet and hail. Hailstones, spherical, of opaque snow formation, four-tenths of an inch in diameter; during fall of hail the atmosphere was highly electrified; the usual buzzing noise, resembling that of bees, came from all pointed objects, as during every electrical storm in its passage over the Peak.

In the thermodynamic studies of Hertz and von Bezold is employed the expression "the hail stage," viz, that stage in which the temperature of  $32^{\circ}$  prevails in an ascending mass of moist air. It is supposed that the ascending air, having already cooled to the dew-point, is carrying up with it a quantity of water, either in small cloud particles or in large raindrops. When these have ascended to the level where the rising moist air is cooled to the temperature of freezing, they continue to give up to the air a little of their specific heat until they are themselves frozen into hail or sleet. There is, therefore, a thin layer of air in which this process of freezing is going on and where the rising mass of mixed air and rain is kept at a uniform temperature until all the water is converted into ice. This is spoken of by Hertz as the hail stage; below it is the rain stage and above it is the snow stage. In this latter region the ascending air, being already cooled below the freezing point, can deposit its moisture only as snow or small crystals of ice. Now, the actual hailstones observed on Pikes Peak are so frequently composed of snow that has been partly melted and refrozen, or mixed with water drops and refrozen, that we can not suppose them to have been wholly formed within the thin layer known as the Hertzian hail stage. It is more likely that they are formed partly within that and partly within the Hertzian snow stage. The memoir of Hertz assumes throughout that the changes of temperature within the ascending air are strictly adiabatic. This requires that the ascent be so slow that the drops of water carried upward maintain the same temperature as the surrounding air. But these two conditions are almost physically incompatible; it is probable that neither of them are ever realized in nature. Among other combinations that are possible and may help to explain the great variety of forms of hailstones that are caught upon the summit of Pikes Peak, we may suggest the two following as the most common:

1. Frozen raindrops carried very rapidly upward through the Hertzian hail stage may continue on into the snow stage and grow by the accretion of snowflakes until they are finally dropped to the earth, in which latter process they continue increasing their snowy covering. If, however, they pass through the hail stage before they reach the ground in their fall, they will be found to consist of an icy nucleus surrounded by a snowy envelope and covered over all by a layer of a frozen mixture of ice and snow.

2. Air that has ascended into the snowy stage without going through the rain or hail stage, or, at least, to a very slight extent, because of its dryness, may form large snowballs high above the Peak before beginning to fall. As such balls descend very rapidly, the interior retains a low temperature,

while the exterior is slightly warmed and melted by the action of the warmer air that the snowballs find near the ground. The result is large hailstones, consisting each of a thin layer or crust of ice and a snowy mass within.

3. In the formation of snow and hail in the midst of ascending currents of air, we must expect to notice the same phenomenon as in the formation of rain, viz, after the first condensations have taken place upon dust and foreign substances the rising mass of cloud represents dustless air in the presence of water particles, but cooled by expansion to such an extent that the air between the drops, or the ice spicules, is in a state of supersaturation. When this condition has become too intense, large quantities of aqueous vapor suddenly condense, rushing together into large drops of rain or large masses of snow, and carrying with them all the finer particles within their respective spheres. At the very low temperatures at which this occurs, water will hold considerable air in solution, and additional air is also included at the center of the snowball among the particles of snow and ice. Such large snowballs are heavy enough to descend rapidly from the snowy stage, through the rain and hail stages to the ground, and in so doing they become saturated with water which recrystallizes forming solid hailstones, but at the center of the mass they still hold, confined, the air originally included in the snowball, and this is compressed under several atmospheres, as was shown in 1869, by P. Reinsch (see Pogg. Ann., 1871, or L. E. D. Phil. Mag. 1871, Vol. XLII., page 79), who observed that when such hailstones are melted under water the little bubble of air at the center is seen to suddenly escape and expand sufficiently to demonstrate the existence of a pressure of 50 atmospheres under which it was confined. In this formation of snowballs and the resulting hail from supersaturated air within the snow stage there is an electric disturbance entirely analogous to that which takes place when great drops of rain are formed within the rain stage. In both cases violent thunder and lightning are observed just before the fall of the hail or the rain.

These and other hypotheses that might be framed relative to the methods of formation of the various kinds of hailstones must, however, only be regarded as suggestions intended to stimulate experimental and theoretical research in this direction. One can not doubt but that the history of the formation of hail is written in its structure if we could but interpret it.

#### STUDIES IN RAINDROPS.

In Popular Science for May, 1900, Mr. W. A. Bentley gives the results of some studies by himself on raindrops.

He catches the drops on a tray full of ordinary flour and finds that the pellet of dough formed at the bottom of each impression is very nearly the actual size of the original raindrop, which vary in diameter from one-fiftieth of an inch to one-fourth of an inch. He finds that the small raindrops are most commonly formed in the lower nimbus or upper cirro-stratus clouds when the intermediate cloud strata are totally absent, or nearly so. Small drops usually form the greater part of the rainfall on the outer edges of the showers and rainstorms, and a large part of the rainfall in all great storms. As a rule the size of the drops progressively increases as we pass from the outer edges to the central portions of showers and rainstorms. The larger drops originate in the upper and intermediate cloud strata, and a vast vertical depth of these clouds is usually necessary to their formation; they frequently come thence with no low clouds present below. The largest drops of all descend from newly formed or forming thundershowers, when cumulus clouds are expanding upward into the cirro-stratus crest that soon forms above and overhangs such showers. Newly formed or forming portions of older showers, and certain circumscribed central portions within the great rain storms, also shed large drops, but rarely are they so large as are those of thundershowers.

The drops of newly formed showers are often large to the extreme edge of the shower, and the rainfall portions of such showers often consist of large and medium drops alone, without small drops intermixed with them. Sometimes large drops fall scatteringly and alone, but more frequently they are associated with both medium and small

drops. The drops from the receding edges of showers and storms are more commonly of larger size than are those of the advancing edge.

A most interesting fact observed is that lightning flashes originate most frequently in that portion of the cloud depositing heaviest rainfall and largest size drops. Here may be the explanation of the absence of lightning flashes in certain showers, as well as the excess of it in others; one may be producing small drops, the other very large ones.

The above results of Mr. Bentley's special study seem to harmonize closely with the Editor's general experience and many special observations that he also has made. Large raindrops seem to require for their formation rapid upward currents; small raindrops and cloud particles are produced in gently rising currents. Fine and gentle rains may fall from the thin horizontal cloud strata that are formed by mixture at the boundary between two currents of different temperatures flowing past each other, but larger drops and heavy rains require a decided cumulus type of cloud and rapidly cooling masses of supersaturated air. Lightning always attends the formation of these large drops of rain or the analogous large snowballs from which hailstones are formed. The hypothesis submitted by the Editor in 1892, and reproduced in *Agricultural Science* in 1892, Vol. VI, p. 307, from which we make the following extract, still seems to be worthy of experimental investigation.

#### THE FORMATION OF LARGE RAINDROPS.

In an article on the production of rain, published in *Agricultural Science* for 1892, Vol. VI, p. 297-309, the present writer reviewed the various hypotheses that have been suggested as to the method of formation of rain, hail, and snow and the possibility of preventing destructive storms. At the close of his article the author said:

As to these various hypotheses that have been suggested concerning the method by which the agglomeration of droplets into large drops is actually effected by nature in her regular process of making rain, I must remark that it is not yet clear to me that any one has demonstrated that small drops actually do agglomerate into larger ones to any considerable extent. I think it quite possible that the union of small cloud particles into larger ones is only effective in driving fogs, or in clouds whose upper surfaces cool by radiation, but is, after all, not an important feature in the natural production of generous rains and summer thundershowers. It is a reasonable working hypothesis that the particles which were originally too small to fall from the clouds with any rapidity actually remain there entangled in the currents of air that characterize clouds, and that they are subsequently evaporated, while, on the other hand, only those fall as rain which, originally, had a size vastly larger than the average size of the smaller particles that constitute the major portion of a cloud. There may be some reason why the condensation of the superabundant molecules of a saturated vapor should form not merely cloud particles whose diameter is ordinarily less than one-hundredth of an inch, but also here and there, large drops which fall to the ground as rain with very much the same size as when originally formed a few moments before in the clouds. The sudden pour of heavy rain from a limited region within a thunder cloud can not be due to a general slow progressive agglomeration of droplets into drops.

On this point I submit the following modification of ideas suggested by reading von Bezold's fourth paper "On the Thermodynamics of the Atmosphere, Berlin, 1892." It suggests a new point of view, and one that demands further experimental elucidation.

Von Bezold suggests that the heavy rains generally known as cloud-bursts are immediately preceded by, and may owe their origin to, a supersaturated state of the atmosphere, by reason of which a greater quantity of vapor is contained in the air than would under other conditions be possible at a given temperature. Following out this hypothesis I conclude that whatever molecular condition it be that permits the existence of a supersaturated atmosphere, it is evident that the removal, or annulment, of that condition must give rise to an immediate and heavy condensation. This principle may be extended to all ordinary rains as well as to the violent thundershowers and cloud-bursts.

The supersaturated condition must be considered as a case of adiabatic expansion,<sup>1</sup> accompanied by a delay in the occurrence of the ap-

propriate condensation; so far as we at present know, this condition can occur only in those cases where all foreign substances, or dust particles, are absent, which might serve as nuclei for the formation of fog particles. A slowly rising and cooling atmosphere first condenses its moisture on the dust nuclei and forms minute droplets; these grow very slowly, by diffusion, up to a definite size proper to the prevailing temperature and vapor tension, but the intermediate air, in which these droplets are floating, keeps on cooling as a dust-free supersaturated vapor. If the sun shines on these droplets its heat powerfully contributes to evaporate them and further saturate the surrounding air.

In general, therefore, the ascending portions of every cloud contain supersaturated, dust-free vapor separating the isolated droplets. When by further expansion and cooling the supersaturation has proceeded to such an extent that further condensation must occur, this latter molecular change permeates the supersaturated space with a rapidity comparable to that with which any other chemical change takes place, just as when the explosive union of chlorine and hydrogen, or of oxygen and hydrogen, starting at any one point, almost instantaneously permeates a mass of those mixed gases, or, as when combustion runs along a train of gunpowder. The vapor molecules from the supersaturated spaces are quickly brought together by their molecular attractions into heavy drops of warm water, which are often distinct from the intermediate cooler droplets, and descend rapidly from the clouds, while the latent heat of condensation is communicated to the adjoining air and is left behind in the cloud. Thus simultaneously with the formation and fall of the big drops there is a sudden expansion of that portion of the clouds from which they came. Von Bezold thinks that such expansion may possibly be felt at the earth's surface as a sudden rise in the barometer, while it is also visible to the eye as a sudden expansion of the cloud into the so-called thunder head. I myself doubt whether there would be any appreciable barometric result, yet I consider that the sudden expansion and ascent of the white cloud and its subsequent rapid dissipation into the surrounding air, together with the simultaneous lightning, thunder, rain, hail, and ascending whirl of wind, all conspire to make it very plausible that there really existed a supersaturated condition at the moment immediately preceding.

If the temperature of the dew-point of the ascending air, or the temperature of supersaturation is below freezing, the condensation of the vapor may at once form, not drops, but large snowflakes, such as will fall rapidly to the ground, or the small hail that is ordinarily called sleet.

Correlated phenomena occur when a cloud consists of small particles of water cooled below the freezing point, as is known to be frequently the case. When for any reason these particles are suddenly converted into ice, as will happen when they are cooled low enough or when they jostle against each other, their temperatures at once rise to the freezing point, a large quantity of heat is set free, the cloud expands and rises, and the droplets of water are converted into spiculæ of ice, or small snowflakes; large flakes and hailstones are not to be explained in this manner.

There is some plausibility in the hypothesis that the critical electrical condition, which results in lightning, is directly due to the disruption of the condition of extreme supersaturation and the sudden formation of large drops of water, or to the disruption of the condition of water cooled below the freezing point, and the consequent sudden formation of ice or snow, but this remains to be investigated.

Therefore, according to this latest view of the subject, the problem of the artificial formation of rain will be partially solved and, sufficiently so for practical purposes, if some method is invented by which to bring about a sudden formation of a small percentage of large drops out of the moist air that exists between the small particles of every cloud.

At present our attention and experiments should be directed toward understanding and completing the natural and obscure process involved in the formation of rain within the cloud and not toward the forcing of any unnatural process.

#### PHOTOGRAPHY IN METEOROLOGY.

The art of photography has proved such an exceedingly useful method of studying and exhibiting meteorological phenomena that it behooves us to stimulate its development and application in every practicable way. Photographs of clouds for the purpose of securing types of the different classifications began to be made as early as photography technically so-called was invented, say, about 1845 (?), and immediately replaced the less satisfactory daguerreotype method of 1839. The use of colored screens, absorbing cells, and polarizing plates which cut off the diffuse light and blue light of the sky, has contributed to the perfection of cloud photographs.

The application of photography to determine the heights

<sup>1</sup> Without adding or subtracting heat.